Optimal Production and Capacity Expansion Planning

Project - TET4135 Energy System Planning and Operation

Spring 2014

Problem description

In this project you will be modeling and analyzing a mixed hydro-thermal power system consisting of three nodes. The nodes are connected by transmission lines with restricted capacity, see Figure 1. This system is a highly simplified and aggregate model of parts of the Nordic power system and its connection to continental Europe. You may consider this an imitation of Norway, Sweden and Germany.

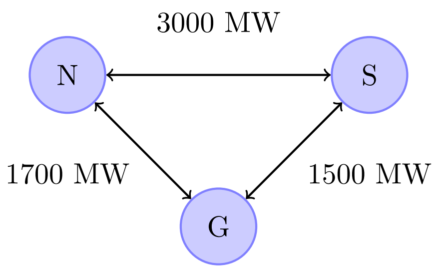

Figure 1: The system with transmission capacities indicated.

You will be provided with a partially complete model of this system defined in PLEXOS. Node N and G are already implemented, but you must complete the model setup by implementing node S according to its system specifications provided below, as well as its interconnections to the other nodes.

System characteristics

Node N

- *Hydro with reservoir:*
  One 23 GW plant connected to a reservoir with a capacity of 84 TWh. The minimum content level for the reservoir is 15 TWh and the initial volume is 60% of maximum capacity. The end volume must also be at 60%. The annual inflow to the reservoir is approximately 100 TWh, and arrives at the reservoir according to a deterministic weekly profile (in MW) given in the file `Inflow_Reservoir_week_pattern.txt`.

- *Small hydro (run-of-river):*
  One 7 GW plant with inflow according to the weekly profile given in the file `Inflow_RoR_week_pattern.txt`.

- *Wind:*
  One plant with a maximum capacity of 630 MW. The production is according to the hourly profile given in the file `Wind_NSG_hour_pattern.txt`

- *Gas:*
  Three units are available, each with a capacity of 450 MW. The heat rate is 7 GJ/MWh.

The annual demand in node N is roughly 130 TWh. The demand is given according to an hourly profile in `Load_N_hour_2014.txt`.

Node G

- *Coal, nuclear and gas:*
  There are several coal, nuclear and gas plants available and their characteristics can be found in Table 1.

- *Oil:*
  10 oil fired power plants are installed. The maximum capacity is 600 MW and the heat rate is 9.2 GJ/MWh.
- *Wind:* There is one plant with a maximum capacity of 30000 MW. The production is according to the hourly profile given in the file `Wind_NSG_hour_pattern.txt`.
- *Solar:* There is one plant with a maximum capacity of 25000 MW. The production is according to the hourly profile given in the file `Solar_G_hour_pattern.txt`.

The annual demand in node G is almost 550 TWh. The demand is given according to an hourly profile in `Load_G_hour_2014.txt`.

Plant	Units	Max capacitiy [MW]	Heat rate [GJ/MWh]	Fuel
Coal 1L	3	2200	8.0	Lignite
Coal 1M	5	900	8.5	Lignite
Coal 1S	12	400	9.0	Lignite
Coal 2L	5	2500	8.0	Hard coal
Coal 2M	10	1000	9.5	Hard coal
Coal 2S	8	300	11.0	Hard coal
Nuclear L	8	1200	9.0	Uranium
Nuclear S	15	500	11.0	Uranium
Gas L	14	900	6.0	Gas
Gas M	16	450	7.0	Gas
Gas S	48	120	9.0	Gas

Table 1: Node G: Plant characteristics

Node S

- *Nuclear:*
  There are 10 nuclear plants installed. Maximum capacity is 1000 MW and the heat rate is 10 GJ/MWh.
- *Coal:*
  There are two coal plants available with a maximum capacity of 450 MW. The heat rate is 7.8 GJ/MWh and they use hard coal as fuel.
- *Gas:*
  Two gas plants with capacity 300 MW are available. The plant's heat rate is 6.7 GJ/MWh.
- *Oil:*
  10 oil fired power plants with an installed capacity of 450 MW. The heat rate is 9.2 GJ/MWh.
- *Biopower:*
  Five direct-fired biomass power plants are available. Each have a maximum capacity of 500 MW and a heat rate of 10.5 GJ/MWh.
- *Hydro with reservoir:*
  One 11 GW plant connected to a reservoir with a capacity of 34 TWh. The minimum

content level for the reservoir is 5 TWh and the initial volume is 60% of maximum capacity. The end volume is also set to 60% of maximum capacity. The annual inflow to the reservoir is given according to a weekly profile in `Inflow_Reservoir_week_pattern.txt`.

- *Small hydro (run-of-river):*
  One 5 GW plant with inflow according to the weekly profile given in the file `Inflow_RoR_week_pattern.txt`.
- *Wind:* There is one plant with a maximum capacity of 2500 MW. The production is according to the hourly profile given in the file `Wind_NSG_hour_pattern.txt`.

The annual demand in node S is roughly 145 TWh. The demand is given according to an hourly profile in `Load_S_hour_2014.txt`.

The fuel prices are equal for all areas and given in the file `Fuel_prices_2014-2034.txt`. The fuels emit CO_2 at the following rates:

- Gas: 56.1 kg/GJ
- Hard coal: 94.6 kg/GJ
- Lignite: 101 kg/GJ
- Oil: 77.4 kg/GJ.

Note: The production files for the renewable sources wind, solar and run-of-river hydro are given in percentage of installed capacity.

Optimal operation for the year 2014

Find the optimal operation plan for this system over one year (2014) by running the medium term (MT) schedule in PLEXOS. Look at the optimal dispatch of the different technologies, transmission between nodes, prices and emissions each week over the year for the three areas. Discuss your findings.

Now, investigate the impacts weather conditions can have on the optimal operation plan for the system. Look at two different scenarios:

- Inflow to the reservoirs is below normal (a dry year). Use the inflow profile given in the file `Inflow_Reservoir_week_pattern_low.txt`.
- Inflow to the reservoirs is above normal (a wet year). Use the inflow profile given in the file `Inflow_Reservoir_week_pattern_high.txt`.

Look at how these different inflow scenarios affect the optimal operation plan for the system compared to normal conditions. What changes and why? Hint: Relevant things to look at can be prices, import/export, load and generation within each area.

Expansion planning

In our simplified model of the Nordic countries and Continental Europe conditions are expected to change over the next 20 years. The demand for electricity decreases in node G, remains fairly constant in node S, while we expect a slight increase in node N. Fuel prices are expected to increase for all types of fuels except lignite, uranium and bio fuel. The three areas want to reduce CO_2 emissions and will also shut down some old nuclear plants. Therefore, they have agreed on a retirement plan for some of the installed thermal capacity over the next 20 years.

The load input files are Load_G_2015_2034.txt, Load_N_2015_2034.txt and Load_S_2015_2034.txt. The file Fuel_prices_2014-2034.txt contains the fuel prices and the retirement plan is given in the file Thermal_Units.txt.

The areas need to invest in new generation capacity and there are several investment options available, shown in Table 2 and 3. Production data for the new wind, solar and small hydro power plants can be found in Wind_NSG_hour_pattern_new.txt, Solar_G_hour_pattern_new.txt and Inflow_RoR_week_pattern_new.txt, respectively. Note that the capacity factors are different for the different options.

In addition to investment in new generation capacity it is also possible to expand transmission capacity between the nodes. The expansion cost is 800, 300 and 600 $/kW for the interfaces G-N, N-S and S-G, respectively. The economic lifetime is 55 years. The maximum possible expansion is given in the file Max_expansion_lines.txt.

Find an optimal expansion plan for this system given the investment options. Implement the model and run the LT plan in PLEXOS (with planning horizon set to 01.01.2015-31.12.2034).

To stimulate increased investments in renewable energy sources and reduce emissions, consider two different approaches:

- **Green certificates**
  As an incentive to invest, new producers of wind, solar and small hydro are awarded with a subsidy per-kWh in addition to market price. The subsidy is set to 50 $/kWh and does not apply to already existing renewable generators. Note that this is a very simplified way of modeling the green certificate market.
- **Emission tax**
  To make renewable producers more competitive, a tax on emission is introduced. The tax on CO_2 is set to 0.05 $/kg.

Given the same system changes and investment options, find the optimal expansion plan for the system under each of the approaches presented above. **Evaluate the optimal expansion plan, present and comment on relevant results and discuss differences between the two approaches. Compare to the situation where no mechanisms to stimulate investments in renewable generation is implemented (other than the retirement plan).**
Relevant results are for example the resulting investment plan (what is built, when and where), prices in the different areas, total emissions, total system cost, total capacity expansion cost and annual production portfolio for the system.

Node	Fuel	Heat rate [GJ/MWh]	Max cap. [MW]	Build cost [$/kW]	Econ. lifetime [years]	Max total exp. [#units]	Max annual exp. [#units/yr]
G	Hard coal	9.3	800	2900	35	15	3
G	Gas	6.0	600	800	35	15	3
G	Uranium	9.5	500	3000	35	10	2

Table 2: Capacity expansion options, thermal.

Node	Tech.	Max cap. [MW]	Build cost [$/kW]	Econ. lifetime [years]	Max total exp. [#units]	Max annual exp. [#units/year]
G	Wind	2	1500	25	15000	1000
G	Solar	5	2500	25	5000	400
N	Wind	2	1500	25	3500	300
N	Small hydro	2	1100	25	8000	1000
S	Wind	2	1500	25	5000	500

Table 3: Capacity expansion options, renewables

Report requirements

It is important that you do the analysis thoroughly an provide a good discussion of your findings in the final report. The report should be approximately 10-15 pages and it should contain:

- **An abstract**:
  10-15 lines where you mention what you have done and state your main results.
- **An introduction:**
  Briefly introduce the system, explain what you have looked at (the objective of your work) and what to expect from your report.
- **A theory/methodology part:**
  This part should include, but need not be limited to:
  - Methods used in the present work. Limitations and simplifications.
  - The handling of intermittent resources like wind, solar and small hydro.
  - The handling of reservoir hydro.
  - The advantages of exchange between regions/countries.
  - Initiatives to stimulate increased investments/generation from renewable sources.
- **An analysis part:**
  Present your results and discuss your findings properly. Good figures and tables are helpful means to communicate results, but do not exaggerate! Do not include figures/tables that you do not refer to in the text.
- **A discussion/conclusion part:**
  Provide a few paragraphs where you discuss important results (maybe something did not turn out as expected?) and state the implications of your work.

Please name your sections, create subsections etc. as you feel appropriate.
Proper citation of sources is not of great importance in this report (as you most likely will mostly use the course material and the PLEXOS documentation). However, you should note that normally proper citation is of great importance in reports and articles.

GOOD LUCK!